SUBCONTRACT TITLE: THE FABRICATION AND PHYSICS OF HIGH-EFFICIENCY CADMIUM-TELLURIDE THIN-FILM SOLAR CELLS

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This progress report covers the third quarter of Phase 2, for the period March 1, 2003, through May 31, 2003, of the above Thin Film Photovoltaic Partnership Program subcontract.

During this quarter, efforts continued on cell fabrication utilizing both SnO_2:F and ZnO:Al as the TCO; on cell fabrication with CdS:O alloys as the window/n-type heterojunction partner; on micrononuniformity studies; on analysis of x-ray fine structure studies carried out at the MRCAT beam line at the Argonne Advanced Photon Source; and on further collaborative work with First Solar on various PL studies of VTD cells.

In this report, we have chosen to highlight our recent results from 1) x-ray absorption fine structure of polycrystalline CdTe with diffused Cu, and 2) electroluminescence vs. temperature in CdS/CdTe devices. We attach two corresponding papers to be published in the Materials Research Society Symposium Proceedings [Symposium B of the MRS conference (San Francisco, California, April 21-25, 2003)]: 1) "Cu K-edge EXAFS in CdTe before and after treatment with $CdCl_2$," by Xiangxin Liu, A.D. Compaan, N. Leyarovska, and J. Terry; 2) "Temperature-Dependent Electroluminescence from CdTe/CdS Solar Cells," by Kent J. Price, A. Vasko, L. Gorrell, and A.D. Compaan.

A brief overview of the two papers is presented below:

Synchrotron x-ray fine structure studies of CdTe:Cu before and after $CdCl_2$ treatments

By using the fine structure in the Cu K-edge x-ray absorption spectrum we are trying to elucidate the lattice location of Cu in polycrystalline, thin-film CdTe solar cells. In particular, we have studied how the typical $CdCl_2$ vapor treatment in dry air changes the local environment of the Cu in CdTe.

Even though a typical concentration of diffused copper in our cells is $1\text{-}2\times10^{20}$ cm^{-3}, capacitance-voltage (C-V) measurements indicate a typical doping concentration of holes a few times 10^{14} cm^{-3}.[A.O. Pudov, M. Gloeckler, S.H. Demtsu, 29th IEEE Photovoltaic Spec. Conf., pp 760-3, IEEE, Piscataway, N.J., 2002] There is considerable interest in where the non-electrically active Cu is located. Our x-ray absorption fine structure measurements lead to the conclusion that films which received the Cu diffusion having no prior treatment with $CdCl_2$ appear to show the Cu mostly bound with Te in neighboring sites similar to Cu_2Te. *However*, if the film, before the Cu deposition and diffusion, had received a $CdCl_2$ treatment, *which for cells*

is always done in the presence of some O_2, then the Cu appears to bind not with Te or Cl but with O. The formation of the wider band-gap cuprous oxide at the CdTe grain boundaries may prevent the recombination of electron-hole pairs there.

Temperature dependence of electroluminescence in CdS/CdTe cells

Using a photomultiplier close-coupled to a CdS/CdTe solar cell mounted in a cryostat, we observed the power dependence of near-band-gap electroluminescence (EL) from the junction under forward bias. From previous measurements, we know that the EL is similar in spectrum to junction photoluminescence with wavelengths from ~1.4 to ~1.6 eV. The EL intensity is measured as a function of drive current and temperature. We find that the EL intensity (I_{EL}) obeys a power law of the form

$$I_{EL} = aI^b,$$

where I is the macroscopic current per unit area and *a* and *b* are constants. We find that the exponential factor, *b*, lies between 1.6 and 2.4 but varies from sample to sample and generally increases as the temperature decreases from room temperature to –30 ^{o}C. Although an exponential factor, *b=1* can occur with electron electron-hole recombination at low injection if, *e.g.*, the injected hole concentration is less than the p-type doping density in CdTe. Conversely, a factor of *b=2* can occur if both electrons and holes are at high injection conditions. However, an exponential factor greater than 2 implies the existence of more complicated phenomena. We suggest that cell nonuniformities, such as observed by Feldman, et al, in micro EL, [S.D. Feldman, F.H. Seymour, T.R. Ohno, V. Kaydanov, and R. Collins, Mat. Res. Soc. Symp. Proc. **763**, paper B5.10, (2003)] *if they are enhanced at low temperature*, could explain an observed current dependence with exponential factors greater than 2. [See also our previous quarterly report, and the paper "The Mesoscale Physics Of Large-Area Photovoltaics" by Victor Karpov, Diana Shvydka, Yann Roussillon, and Alvin Compaan, presented at the 29th IEEE Photovoltaics Specialists Conference (Osaka, Japan, May 12-16, 2003).]

Attachment 1: "Cu K-edge EXAFS in CdTe before and after treatment with $CdCl_2$," by Xiangxin Liu, A.D. Compaan, N. Leyarovska, and J. Terry, Mat. Res. Soc. Symp. Proc. **763**, paper B3.5, (2003).

Attachment 2: "Temperature-Dependent Electroluminescence from CdTe/CdS Solar Cells," by Kent J. Price, A. Vasko, L. Gorrell, and A.D. Compaan, Mat. Res. Soc. Symp. Proc. **763**, paper B5.9, (2003).